HYBRID DC-DC CONVERTERS FOR POWER AMPLIFIERS

[0001] The subject matter described herein relates to direct-current to direct-current (DC-DC) converters.

BACKGROUND

[0002] Direct-current to direct-current (DC-DC) converters are used in a wide variety of consumer and industrial products including desktop computers, printers, laptops, and cell phones. In some products, the efficiency a DC-DC converter is not of particular importance. However, in other types of products efficiency is important, particularly when the product is battery-powered. In battery-powered products, efficiency translates to longer operating time and fewer recharges of the battery.

SUMMARY

[0003] Methods and apparatuses, including computer program code are disclosed herein that provide a hybrid DC-DC converter.

[0004] In one aspect, there is provided a method. The method may include tracking, by an envelope detector, an envelope of a signal being amplified by an amplifier. The method may further include supplying, by a first direct-current to direct-current converter, power to the amplifier, the power supplied by the first direct-current to direct-current converter including one or more high-frequency components of the envelope tracked by the envelope detector. The method may further include supplying, by a second direct-current to direct-current converter, power to the amplifier, the power supplied by the second direct-current to direct-current converter including one or more low-frequency components of the envelope tracked by the envelope detector.

[0005] In some variations, one or more of the features disclosed herein including the following features can optionally be included in any feasible combination. A power amplifier may be coupled to the envelope detector, the first direct-current to direct-current converter, and the second direct-current to direct-current converter. The first direct-current to direct-current converter may be characterized by a frequency response defined at least in part by a fast ramp voltage. The second direct-current to direct-current converter may be characterized by a frequency response defined at least in part by a slow ramp voltage. The transistor widths of the first direct-current to direct-current converter may be between about 500 microns and about 1000 microns in a 65 nanometer semiconductor process. The transistor widths of the second direct-current to direct-current converter may be between about 5 millimeters and about 10 millimeters in a 65 nanometer semiconductor process.

[0006] The above-noted aspects and features may be implemented in systems, apparatuses, methods, and/or computer-readable media depending on the desired configuration. The details of one or more variations of the subject matter described herein are set forth in the accompanying drawings and the description below. Features and advantages of the subject matter described herein will be apparent from the description and drawings, and from the claims. In some exemplary embodiments, one of more variations may be made as well as described in the detailed description below and/or as described in the following features.

DESCRIPTION OF DRAWINGS

[0007] In the drawings,

[0008] FIG. **1**A depicts a system including a hybrid switching DC-DC converter, in accordance with some example embodiments;

[0009] FIG. **1**B depicts a process for a hybrid DC-DC converter to supply power to a power amplifier, in accordance with some example embodiments;

[0010] FIG. **2** depicts a schematic diagram of a hybrid switching DC-DC converter, in accordance with some example embodiments;

[0011] FIG. **3** depicts a schematic diagram of a deadtime control circuit, in accordance with some example embodiments;

[0012] FIG. **4** depicts examples of waveforms produced by a hybrid switching DC-DC converter, in accordance with some example embodiments; and

[0013] FIG. **5** depicts a block diagram of an apparatus that can be configured as user equipment, in accordance with some example embodiments.

[0014] Like labels are used to refer to same or similar items in the drawings.

DETAILED DESCRIPTION

[0015] The high peak-to-average power ratio (PAPR) required by some devices compliant with communication standards, such as the Long Term Evolution series of standards and the like, may cause excessive power dissipation in the transmitter power amplifier. By tracking the envelope of a signal being amplified by the power amplifier, the power supply voltage and/or current (or "supply power") to the power amplifier may be adjusted according to the envelope. Supply power is the voltage and/or current supplied to the power amplifier in order for the power amplifier to operate. Traditionally, the supply power is direct current voltage and current with a constant value. In the embodiments disclosed herein, the supply power (voltage and/or current) vary over time according to the envelope of the signal being amplified by the power amplifier. Adjusting the supply power according to the envelope may reduce the power dissipated in the power amplifier. Moreover, adjusting the supply power of the power amplifier according to the envelope may increase the power efficiency of the power amplifier. In some example embodiments, the power efficiency may be determined as a ratio of the radio frequency power available at the output of the power amplifier divided by the average DC power supplied to the power amplifier, although other determinations of efficiency may be used as well.

[0016] To adjust the supply power to the power amplifier according to a rapidly varying envelope of a signal being amplified by the power amplifier may require that the DC-DC converter supplying power to the power amplifier have a wide bandwidth. In some example embodiments, the bandwidth of a switching DC-DC converter depends on the switching frequency of the converter. Higher bandwidths require higher switching frequencies. However, increasing the switching frequency above a certain practical value may result in unacceptable switching losses in the output transistors. As the power required by the power amplifier increases, output transistors that are physically wider may be needed. While the conductive losses in transistors may decrease with wider transistor widths, switching losses may increase. As a result, transistor widths beyond a predetermined value become